Cost Effective Analysis using Life Cycle Cost Analyses

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ACPA

ACPTP
Airport Concrete Pavement Technology Program

Learning Objectives

- Explain the critical factors that should be considered when selecting design pavement section
- Comprehend the fundamentals of life-cycle cost analysis for airfield pavement
- Develop basic maintenance strategies necessary for performing life-cycle costing
- Determine the functional life for rigid and flexible pavements
- Understand how to determine analysis period and discount rate
- Perform a basic life-cycle cost analysis and make a pavement design selection

Cost Effectiveness Determination (1.6.3)

- 1.6.3.1 A cost effectiveness determination includes a life-cycle cost analysis (LCCA). LCCA methodology includes the following steps
  - Establish Alternative design strategies
  - Determine activity timing (analysis period that includes at least one rehabilitation of each alternative)
  - Estimate direct costs (estimate future costs in constant dollars and discount to present using real discount rate)

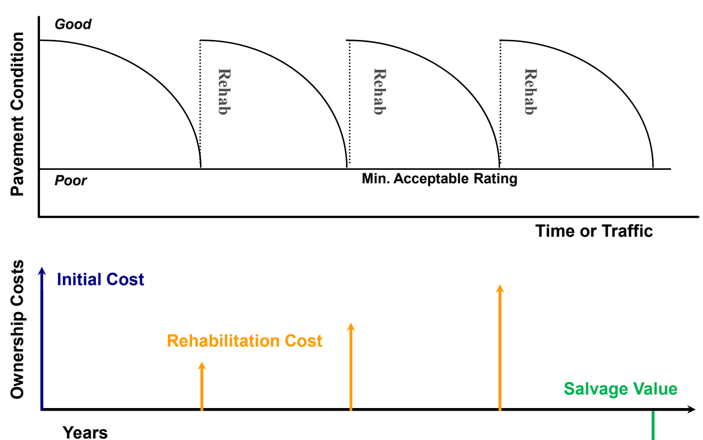
  Note: Analysis period is the length of time over which alternative pavement sections are compared and is not necessarily the design life used for the pavement design. Coordinate analysis periods to be evaluated with owner and FAA on federally funded projects. Document LCCA in the engineer's report on federally funded projects.

- 1.6.3.2 Routine maintenance costs, such as incidental crack sealing, have a marginal effect on net present value (NPV). Focus on initial construction, planned preventative maintenance, and rehabilitation costs. Base salvage value on the remaining functional life of an alternative at the end of the analysis period

LIFE CYCLE COST ANALYSIS IS PROJECT ANALYSIS TOOL THAT QUANTIFIES THE TOTAL "COSTS OF OWNERSHIP"

Accounts for initial costs and discounted future rehabilitation costs

Acknowledgement: Jim Mack, P.E., MBA



LCCA compares different options for a given project and determines which pavement design is most cost effective over the analysis period

$$NPV = \text{Initial Cost} + \sum Rehab\ cost \times \frac{1}{(1+d)^{n_k}} - Salvage\ Value \times \frac{1}{(1+d)^{n_k}}$$

Where
NPV = Net Present Value
d = real discount rate
n_k = year of expenditure

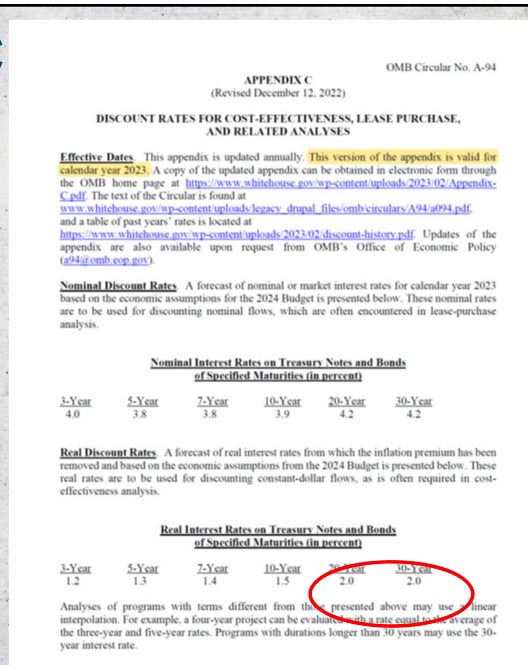
CEMEX

Cost Effectiveness Determination References

- Airfield Asphalt Pavement Technology Program (AAPTP) Report 06-06 *Life-Cycle Cost Analysis for Airport Pavements*
  - Developed LCCA process that is currently in FAA PAVEAIR (more on this later)
- Federal Highway Administration *Life-Cycle Cost Analysis Primer*
- Office of Management and Budget (OMB) Circular A-94, Appendix C *Discount Rates for Cost-Effectiveness, Lease Purchase, and Related Analyses*
- FAA Program Guidance Letter (PGL) 22-01 *Guidance on discount rate application for cost effectiveness for airfield pavement projects*
  - https://www.faa.gov/airports/aip/guidance_letters/media/AIP-PGL-22-01-discount-rate-pavement-projects.pdf

OMB Circular A-94 Appendix C

- OMB Circular A-94 provides guidance to federal agencies on performing Benefit-Cost Analysis and Cost-Effectiveness Analysis.
- Circular is not mandatory for use, agencies can establish their own procedures
- Appendix C is updated annually with discount rates to be used for the current calendar year.
- https://www.whitehouse.gov/wp-content/uploads/2022/05/Appendix-C.pdf



OMB Circular No. A-94

APPENDIX C
(Revised December 12, 2022)

DISCOUNT RATES FOR COST-EFFECTIVENESS, LEASE PURCHASE, AND RELATED ANALYSES

Effective Dates. This appendix is updated annually. This version of the appendix is valid for calendar year 2023. A copy of the updated appendix can be obtained in electronic form through the OMB home page at https://www.whitehouse.gov/wp-content/uploads/2023/02/Appendix-C.pdf. The text of the Circular is found at www.whitehouse.gov/wp-content/uploads/legacy_drupal_files/omb/circulars/A94/a094.pdf, and a table of past years' rates is located at https://www.whitehouse.gov/wp-content/uploads/2023/02/discount-history.pdf. Updates of the appendix are also available upon request from OMB's Office of Economic Policy (a94@omb.eop.gov).

Nominal Discount Rates. A forecast of nominal or market interest rates for calendar year 2023 based on the economic assumptions for the 2024 Budget is presented below. These nominal rates are to be used for discounting nominal flows, which are often encountered in lease-purchase analysis.

Nominal Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
4.0	3.8	3.8	3.9	4.2	4.2

Real Discount Rates. A forecast of real interest rates from which the inflation premium has been removed and based on the economic assumptions from the 2024 Budget is presented below. These real rates are to be used for discounting constant-dollar flows, as is often required in cost-effectiveness analysis.

Real Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
1.2	1.3	1.4	1.5	2.0	2.0

Analyses of programs with terms different from those presented above may use a linear interpolation. For example, a four-year project can be evaluated with a rate equal to the average of the three-year and five-year rates. Programs with durations longer than 30 years may use the 30-year interest rate.

Determining Present Worth of Alternative

- The basic equation:

$$\mathrm{PW} = C + \sum_{i=1}^{m} M_i \left(\frac{1}{1+r}\right)^{n_i} - S\left(\frac{1}{1+r}\right)^{z}$$

Where:

PW	=	Present Worth
C	=	Present Cost of initial design or rehabilitation activity
m	=	Number of maintenance or rehabilitation activities
M_i	=	Cost of the ith maintenance or rehabilitation alternative in terms of present costs, i.e., constant dollars
r	=	Discount rate
n_i	=	Number of years from the present of the ith maintenance or rehabilitation activity
S	=	Salvage value at the end of the analysis period
Z	=	Length of analysis period in years.

$\left(\frac{1}{1+r}\right)^{n}$ is commonly called the single payment present worth factor in most engineering economic textbooks

Looking at the Terms

$\mathrm{PW} = C +$ [redacted] $- S\left(\frac{1}{1+r}\right)^{z}$

- C – What is your estimated cost to construct the alternative.
- *z* – Analysis period should include at least one rehabilitation cycle for each alternative.
  - Typically, the analysis period is set as the shortest functional life of the alternatives
- S – Salvage value is 0 if functional life = analysis period.
  - If functional life remains straight-line depreciate value of the alternative at the end of the analysis period.
- *r* – Real Discount Rate based on analysis period (OMB A-94 Appendix C)

What does this term tell us?

$$PW = [redacted] + \sum_{i=1}^{m} M_i \left(\frac{1}{1+r} \right)^{n_i} [redacted]$$

- M_i – Iterate for each maintenance and rehab activity in analysis period
- n_i – Years from initial construction to activity
- *r* – Real Discount Rate based on analysis period (OMB A-94 Appendix C)

Example LCCA - Alternates

Project: Construct new 60,000 Square yard parking apron

Alternates:

Concrete Pavement (12 in)	Asphalt Pavement (4 in)
Initial Construction Costs	**Initial Construction Costs**
12 in PCC, $58.32/yd^2	4 in Asphalt, $30.11/yd^2
5 in Stabilized Base, $31.50/yd^2	5 in Stabilized Base, $31.50/yd^2
6 in Aggregate Base, $18/yd^2	10 in aggregate base, $26/yd^2
Functional Life	**Functional Life**
45 years	30 years

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Example LCCA – Maintenance & Rehab Activities

Concrete Pavement (12 in)	Asphalt Pavement (6 in)
M&R Costs	**M&R Costs**
Joint/Crack Seal, Spall Repair, $4.35/yd^2	Crack Seal, $3.13/yd^2
Joint/Crack Seal, Spall Repair, slab replacement, $17.50/yd^2	Seal Coat, $1.50/yd^2
	2 in mill and overlay, $25.86/yd^2
M&R Schedule	**M&R Schedule**
Yr. 7, Joint/Crack Seal, Spall Repair (Mx.)	Yr. 4, Crack Seal (Mx.)
Yr. 15, Joint/Crack Seal, Spall Repair (Mx.)	Yr. 8, Crack Seal, Seal Coat (Mx.)
Yr. 20, Joint/Crack Seal, Spall Repair, Slab Replacement (rehab)	Yr. 12, Crack Seal (Mx.)
Yr. 27, Joint/Crack Seal, Spall Repair (Mx.)	**Yr. 15, Mill and Overlay (rehab)**
Yr. 35, Joint/Crack Seal, Spall Repair (Mx.)	Yr. 19, Crack Seal (Mx.)
Yr. 40, Joint/Crack Seal, Spall Repair (Mx.)	Yr. 23, Crack Seal, Seal Coat (Mx.)
	Yr. 27, Crack Seal (Mx.)

Example LCCA – Solve the easy parts

$PW = C +$ [redacted]

- C – Estimated cost to construct the alternative (60,000 yd^2).

Concrete Pavement (12 in)	Asphalt Pavement (6 in)
Initial Construction Costs	**Initial Construction Costs**
12 in PCC, $58.32/yd^2	4 in Asphalt, $30.11/yd^2
5 in Stabilized Base, $31.50/yd^2	5 in Stabilized Base, $31.50/yd^2
6 in Aggregate Base, $18/yd^2	10 in aggregate base, $26/yd^2
$6,469,200	**$5,256,600**

Example LCCA – Solve the easy parts

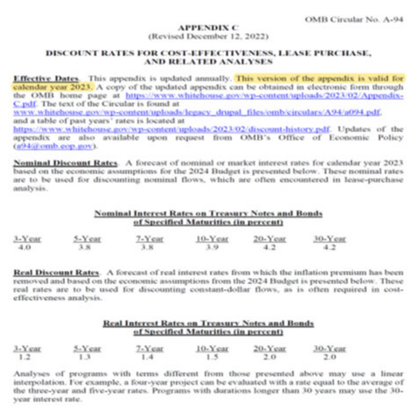
$$\text{PW} = \text{[redacted]} - S\left(\frac{1}{1+r}\right)^{z}$$

- *z* – Analysis period should include at least one rehabilitation cycle for each alternative.
  - Asphalt: Rehab = 15 years, Functional Life = 30 years
  - Concrete: Rehab = 20 years, Functional Life = 45 years
- 20-year analysis includes one rehab, but leaves salvage value for both alternatives
- 30-year analysis leaves salvage value for concrete alternative only
- 45-year analysis requires a reconstruction of asphalt alternative and would leave salvage value for asphalt alternative

Example LCCA – Solve the easy parts

$$\text{PW} = \text{[redacted]} - S\left(\frac{1}{1+r}\right)^{z}$$

- *r* – Real Discount Rate based on analysis period (OMB A-94 Appendix C)



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Analyses of programs with terms different from those presented above may use a linear interpolation. For example, a four-year project can be evaluated with a rate equal to the average of the three-year and five-year rates. Programs with durations longer than 30 years may use the 30-year interest rate.

How do we handle salvage value

$$\mathrm{PW} = \qquad - S\left(\frac{1}{1+r}\right)^{z}$$

- S – Salvage value is 0 if functional life = analysis period.
- If functional life remains straight-line depreciate value of the alternative at the end of the analysis period.

Concrete Pavement (12 in)	Asphalt Pavement (6 in)
Initial Construction Costs	**Initial Construction Costs**
$6,469,200	$5,256,600.00
Life Remaining	**Life Remaining**
45-30 = 15 years	30-30 = 0 years
S = $2,156,400	**S = $0**

Example LCCA – Where do we stand?

$$\mathrm{PW} = C + \sum_{i=1}^{m} M_i\left(\frac{1}{1+r}\right)^{n_i} - S\left(\frac{1}{1+r}\right)^{z}$$

- PW_{PCC} = $6,469,200 + $\sum_{i=1}^{m} M_i\left(\frac{1}{1+r}\right)^{n_i}$ - $2,156,400 (1/(1+.02))^{30}
- **PW_{PCC} = $6,469,200 +** $\sum_{i=1}^{m} M_i\left(\frac{1}{1+r}\right)^{n_i}$ **- $1,190,486**
- **PW_{AC} = $5,256,600 +** $\sum_{i=1}^{m} M_i\left(\frac{1}{1+r}\right)^{n_i}$ **- $0**

Maintenance & Rehab Costs - Concrete

$$\sum_{i=1}^{m} M_i \left(\frac{1}{1+r}\right)^{n_i}$$

- M_i – Maintenance/Rehab Present Cost
- n_i – Years from initial construction to activity
- *r* – Real Discount Rate based on analysis period

Concrete Pavement (12 in)
M&R Costs
Joint/Crack Seal, Spall Repair, \$4.35/yd²
Joint/Crack Seal, Spall Repair, slab replacement, \$17.50/yd²
M&R Schedule
Yr. 7, Joint/Crack Seal, Spall Repair (Mx)
Yr. 15, Joint/Crack Seal, Spall Repair (Mx)
Yr. 20, Joint/Crack Seal, Spall Repair, Slab Replacement (rehab)
Yr .27, Joint/Crack Seal, Spall Repair (Mx)
Yr. 35, Joint/Crack Seal, Spall Repair (Mx)

Year	Present Cost	Net Present Value
7	\$261,000	\$227,216
15	\$261,000	\$193,927
20	\$1,050,000	\$706,619
27	\$261,000	\$152,909
Net Present Value of Maintenance and Rehab		
\$1,280,672		

Example LCCA – Maintenance & Rehab Costs - Asphalt

$$\sum_{i=1}^{m} M_i \left(\frac{1}{1+r}\right)^{n_i}$$

- M_i – Maintenance/Rehab Present Cost
- n_i – Years from initial construction to activity
- *r* – Real Discount Rate based on analysis period

Asphalt Pavement (6 in)
M&R Costs
Crack Seal, \$3.13/yd²
Seal Coat, \$1.50/yd²
2 in mill and overlay, \$25.86/yd²
M&R Schedule
Yr. 4, Crack Seal (Mx)
Yr. 8, Crack Seal, Seal Coat (Mx)
Yr. 12, Crack Seal (Mx)
Yr. 15, Mill and Overlay (rehab)
Yr 19, Crack Seal (Mx)
Yr 23, Crack Seal, Seal Coat (Mx)
Yr 27, Crack Seal (Mx)

Year	Present Cost	Net Present Value
4	\$187,800	\$173,498
8	\$277,800	\$237,100
12	\$187,800	\$148,079
15	\$1,551,600	\$1,152,862
19	\$187,800	\$128,912
23	\$277,800	\$176,169
27	\$187,800	\$110.025
Net Present Value of Maintenance and Rehab		
\$2,126,644		

Example LCCA – Present Worth

$$PW = C + \sum_{i=1}^{m} M_i \left(\frac{1}{1+r} \right)^{n_i} - S \left(\frac{1}{1+r} \right)^{z}$$

- PW_{PCC} = $6,559,386
  - PW_{AC} = $7,383,244
  - Percent Difference: 13%

Example LCCA – Don't Sweat the Math

	A	B	C	D	E
1	**Life-Cycle Cost Analysis**				
2					
3	Analysis Period	30	Years		
4	Discount Rate	0.50%			
5					
6	Present Worth	$6,285,139			
7					
8	**Initial Construction**				
9					
10	Area:	60000	yd^2		
11					
12	Material Type	Unit Cost (yd^2)	Total		
13	12 in PCC	$58.32	$3,499,200		
14	5 in Stabilized Base	$31.50	$1,890,000		
15	6 in Aggregate Base	$18.00	$1,080,000		
16		Total	$6,469,200		
17					
18	**Maintenance**				
19	Year	Unit Cost	Present Cost	Present Worth Factor	Net Present Value
20	7	$4.35	$261,000.00	0.96568963	$252,045
21	15	$4.35	$261,000.00	0.927916877	$242,186
22	20	$17.50	$1,050,000.00	0.905062904	$950,316
23	27	$4.35	$261,000.00	0.874009861	$228,117
24			$0.00	1	$0
25			$0.00	1	$0
26			$0.00	1	$0
27			$0.00	1	$0
28			$0.00	1	$0
29			$0.00	1	$0
30			$0.00	1	$0
31			$0.00	1	$0
32					
33				Total	$1,672,664
34					
35	**Salvage Value**				
36					
37	Functional Life	45	years		
38					
39	Salvage Value	$2,156,400			
40	Salvage Value (PW)	$1,856,725			

	A	B	C	D	E
1	**Life-Cycle Cost Analysis**				
2					
3	Analysis Period	30	Years		
4	Discount Rate	0.50%			
5					
6	Present Worth	$7,906,922			
7					
8	**Initial Construction**				
9					
10	Area:	60000	yd^2		
11					
12	Material Type	Unit Cost (yd^2)	Total		
13	4 in Asphalt	$30.11	$1,806,600		
14	5 in Stabilized Base	$31.50	$1,890,000		
15	10 in Aggregate Base	$26.00	$1,560,000		
16		Total	$5,256,600		
17					
18	**Maintenance**				
19	Year	Unit Cost	Present Cost	Present Worth Factor	Net Present Value
20	4	$3.13	$187,800.00	0.980247522	$184,090
21	8	$4.63	$277,800.00	0.960885204	$266,934
22	12	$3.13	$187,800.00	0.94190534	$176,890
23	15	$25.86	$1,551,600.00	0.927916877	$1,439,756
24	19	$3.13	$187,800.00	0.909588219	$170,821
25	23	$4.63	$277,800.00	0.891621597	$247,692
26	27	$3.13	$187,800.00	0.874009861	$164,139
27			$0.00	1	$0
28			$0.00	1	$0
29			$0.00	1	$0
30			$0.00	1	$0
31			$0.00	1	$0
32					
33				Total	$2,650,322
34					
35	**Salvage Value**				
36					
37	Functional Life	30	years		
38					
39	Salvage Value	$0			
40	Salvage Value (PW)	$0			

Cost Effectiveness Determination (1.6.3)

- Thoughts on performing a quality Life-Cycle Cost Analysis
  - Analysis period should include at least one rehabilitation for each alternative
  - Discount Rates should reflect analysis period
  - Try to use realistic maintenance activities and timings for the specific airport, or similar airports in the region.
    - Statewide pavement management system plan can help
  - Use realistic pavement functional life for each alternative. Base on historical trends at the airport and similar airports in the region.
  - Sensitivity Analysis should be performed to address variability of major input assumptions
- 1.6.3.3 An LCCA in support of a pavement section does not ensure that funds will be available to support the initial construction
- 1.6.3.6 From a practical standpoint, if the difference in the present worth of costs between two design or rehabilitation alternatives is 10 percent or less, it is normally assumed to be insignificant and the present worth of the two alternatives can be assume to be the same.

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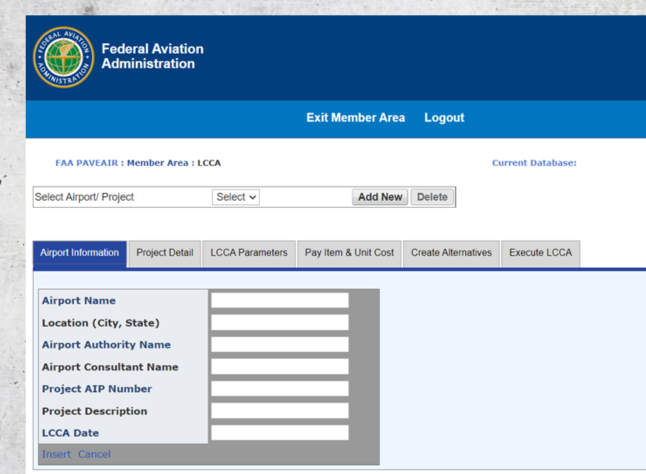
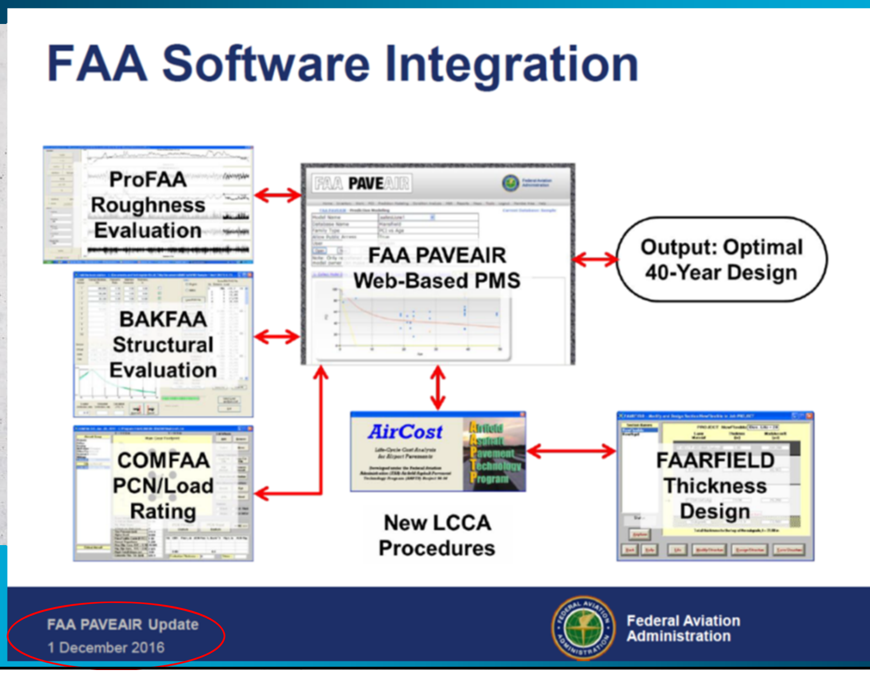
Cost Effectiveness Determination

- Other Factors to Consider
  - Statistical Computational Approach
  - Supplemental Direct Costs (i.e. engineering)
  - Indirect/User Costs (i.e. aircraft delay costs)
- LCCA can get complicated fast
- AAPTP Report 06-06
  - Provides a framework to perform LCCA for airfield pavements
  - Developed AirCost tool as Excel application (Appendix C)
  - AirCost integrated into FAA PAVEAIR
  - Current FAA PAVEAIR includes modernized user interface.
    - https://faapaveair.faa.gov/DataManagement/LCCA.aspx





Other Factors

- The selection of a pavement section requires the evaluation of multiple factors including:
  - Cost and funding limitations
  - Operational constraints
  - Construction timeframe
  - Material availability
  - Cost and frequency of anticipated maintenance
  - Environmental constraints
  - Future airport expansion plans
  - Anticipated changes in traffic

- Document the rationale for the selected pavement section, materials and service life in the engineer's report.

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